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Dimensions of the acoustic reflex as measured in a background of noise

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DIMENSIONS OF THE ACOUSTIC REFLEX AS MEASURED IN A BACKGROUND OF NOISE

INDEPENDENT STUDY 1978-1979
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With the advent of impedance audiometry, measurement of acoustic admittance changes afforded by the middle ear has become a relatively simple operation. This simplicity has lent itself to a variety of clinical and experimental applications, particularly the recording of impedance changes brought about by the reflexive activity of middle ear musculature in response to loud sound.

There have been several studies dealing with acoustic reflex (AR) characteristics in relation to noise-induced threshold shifts. Johansson et al. (1967) found that subject differences in AR latencies, rise time and strength of response correlated quite closely with the degree of temporary threshold shift which could be induced by some set stimulus. In addition, Fletcher and Riopelle (1960) seem to have hinted at a complex interaction between perstimulatory activity in the reflex arc and the actual response obtained by demonstrating less serious threshold shifts from impulsive noise when AR was elicited before and during presentation of these sounds.

We might suspect a possible although unproven relation between the results of these two studies in that Fletcher and Riopelle may have altered some characteristics of the AR in such a manner as to acquire results which were compatible with the Johansson data. Taking the idea a step further, we could suggest that the variability in AR existing between subjects may even represent factors intrinsic to the individual. The protective mechanism may not actually exhibit a single set of properties; AR characteristics might depend, to an extent, on the conditions present before application of the stimulus. We already know this to be fact for the different psychological and physiological states of the subject (Borg and Møller, 1967; Lidén et al., 1974). In response to acoustic stimulation, there could conceivably be an alteration based on the neural discharge and degree of recordable and/or unrecordable muscular contraction present before the reflex is either elicited or augmented.

Recently, Jerger (1979) has been employing signal-averaging techniques to measure AR, the results of which indicate that AR causes recordable changes in admittance at lower stimulus intensities than those levels achieved with equipment designed for clinical impedance audiometry (unpublished data). Using these signal-averaging method, one may be monitoring the contraction of some fibres within the stapedius muscle and would consequently be finding changes occurring at comparatively lower sound levels.

The evidence from Johansson et al.(1967), Fletcher and Riopelle (1960) and Jerger (1979) suggest that sound stimulation, which is not sufficient to elicit a recordable AR response, may cause a small degree of activation in the reflex which in turn results in contraction of some fibres in the stapedius muscle.

The purpose of this study is to determine whether background noise (one-third-octave wide),presented at 10 dB below its reflex threshold, affects the AR response for pure tones presented subsequent to the onset of the noise. The relative intensity level of the noise was chosen to represent a situation which occurs in everyday life. That is, there is often no better that a 10 dB siganl-to-noise ratio between speech and background noise, especially in the frequency region below 1000 Hz. Although the intensity levels which elicit a recordable AR are higher than those encountered under typical listening conditions (Pearsons et al., 1976), they do represent realistic estimates of sound levels delivered by a hearing aid or encountered in noisy environments (e.g., factories, sporting events and musical concerts). Consequently, it is believed that the results of this study may have implications for two types of listeners: hearing aid users and individuals exposed to higher than usual levels of sound stimulation. If the results indicate that the background noise has an effect on the AR response, then we may need to consider changes in our clinical procedures for evaluating the AR, obtaining uncomfortable-loudness-level (UCL) judgements and estimating the desirable maximum power output of a hearing aid. If there are no significant effects, then we should not need to consider such changes.

METHOD

A. EQUIPMENT

Figure 1 is a schematic representation of the equipment used in this study. One-third-octave bands of noise were created by passing the signal from a random noise generator (General Radio Company, Type 1390-B) through a pink noise filter (General Radio Company, Type 1390) and then to specially constructed active filter testers (500 and 2000 Hz). The resultant narrow-band noises (NBN) had a sharp-skirt configuration which closely approximated critical ratios in their bandwidth (Scharf, 1970). These sounds were recorded on tape (Scotch, #206) using a Sony tape recorder (TC-645, left channel, 19 cm/sec tape speed). Playback was through an Akai tape player (1722W, left channel, 19 cm/sec tape speed).

Pure tone (PT) stimuli were generated by a Krohn-Hite oscillator (Model 4100). The RMS voltage and frequency of the oscillator output were monitored respectively by an electronic voltmeter (Ballantine, Model 300) and frequency counter (Hewlett-Packard, Model 5300A).

The mixer (Grason-Stadler audiometer, Model 1701) was set to deliver the PT stimulus (External 1 input to the audiometer, channel 1) and NBN (Tape A input to the audiometer, channel 2) to the left earphone (Telephonics TDH-49). Signal amplitude was maintained at 6.1 volts (+3/4 VU on the audiometer). The VU meter reading for the noise was between -3 to -5 on the tape player and averaged -3.5 on the audiometer. These settings optimized the levels of the signals as measured in a 6cc coupler (Brüel and Kjaer, #4151) by a sound level meter (Brüel and Kjaer, #2203) using a one-inch condensor microphone (Brüel and Kjaer, #4132). No PT or NBN surpassed 110 dB SPL (re 20 μPa) by band measurements because at this point unacceptable distortion was introduced into the system, e.g., non-linear attenuation as well as harmonic and intermodulation distortion. Also, for the protection of the listeners, we did not wish to expose anyone to higher levels than this.

The changes in susceptance, monitored at the ear contralateral to the PT and/or NBN stimuli, were measured with a Grason-Stadler otoadmittance meter (Model 1702B). This instrument has an AVC circuit which adjusts the sound pressure level of the probe tone so that the resultant level at the probe microphone remains constant. The susceptance measure is based on a comparison of the phase and intensity level of the probe tone with that part of the resultant signal which is 90° out of phase with the probe tone.

Since Wilson and McBride (1978) demonstrated the greater sensitivity of the 660 Hz probe to AR threshold (as compared to a lower frequency probe), changes in susceptance measured with this frequency probe were employed. This choice was not, however, without some drawbacks, as we shall discuss in a subsequent section.

Voltage output from the susceptance multiplier on the otoadmittance meter was fed to an oscilloscope (Tektronix, Model 7313) calibrated to 0.5 volts/division along the ordinate and 5 μsec/division on the abscissa. This resulted in a relatively straight-line readout (with minimal baseline activity) which moved in a vertical direction with changes in susceptance produced by the middle ear muscles.

B. SUBJECTS

1. Normal

All prospective subjects were screened audiometrically. Criteria for participation in the experiment included:

a. Pure tone thresholds 10 dB HL or better bilaterally at 500, 1000 and 2000 Hz (to eliminate, with reasonable certainty, pathologies which might interfere with data collection).

b. Normal tympanogram (pressure and shape) in the ear to be monitored for susceptance changes.

c. Normal AR threshold.

A total of six listeners (three female, three male) met these criteria for normality. Their ages ranged from 21 to 27 years and all participants were in good general health.

2. Hearing-Impaired

Two female subjects with mild (30 dB HL), mixed hearing losses at the frequencies tested in this study were included to explore what results might be expected for hearing-impaired listeners. Their ages were 21 and 25 and they were in good physical condition.

C. PROCEDURE

Identical procedures were used to measure threshold of reflex activity and growth of response with increasing sound intensity with PT stimuli presented against a background of noise and quiet. Noise bands and tones were chosen so that we could examine any frequency dependence in activity that might exist inside and outside bandwidths defined by critical ratios (Scharf, 1970). Two pure tones were chosen from within the frequency region in which the AR causes maximal change in the admittance of sound at the eardrum (500 and 1000 Hz), and one tone from outside this frequency range (2000 Hz). Each noise band was chosen so that the tones were centered within its bandwidth (as defined by critical ratios) or lay outside this bandwidth. This enabled us to look at the frequency dependency of AR inside and outside of the critical ratio. The intensity level of the noise- 10 dB below AR threshold for the NBN- was selected for two reasons:

1. In order to represent a signal-to-noise ratio common in everyday life.
2. Electromyographic studies have shown that recordable muscular contraction is initiated before measureable changes in impedance occur, at sound pressures 5-6 dB less than those achieved electroacoustically (Zabrisson et al., 1974).

Measurements of susceptance were performed under the following conditions:

A. Without Noise

1. PT stimuli (500, 1000 and 2000 Hz) of approximately one-second duration were employed to evaluate their effect on:

a. threshold of AR

b. growth of AR (4 dB steps of increasing intensity, beginning with threshold).

B. With Noise

1. NBN centered at 500 Hz

a. set noise level at -10 dB re AR threshold for 500 Hz NBN

b. evaluate threshold and growth of AR for 500 Hz PT

c. evaluate threshold and growth of AR for 1000 Hz PT

2. NBN centered at 2000 Hz

a. set noise level at -10 dB re AR threshold for 2000 Hz NBN

b. evaluate threshold and growth of AR for 1000 Hz PT

c. evaluate threshold and growth of AR for 2000 Hz PT.

Selection of ears to be tested on each subject and order of presentation of stimuli with respect to condition (noise vs quiet) were randomized by the experimenter in order to avoid ear and adaptation effects.

Measurement of changes in susceptance caused by the AR were performed in the ear contralateral to the stimulus. All evaluations were conducted at 0mmH_2O since all subjects gave normal pressure readings in the screening. AR thresholds were defined as a just noticeable difference in baseline activity on the oscilloscope. Noise was switched on 10 or more seconds before the tone in order to insure that the noise was exerting some influence on the reflex system prior to the presentation of the tone. This interval was chosen to exceed the 30-200 msec latency of onset of the stapedial reflex and was related in part to the logistics of the test situation.

As an ancillary to our investigation, apparent loudness judgements were required of each subject under the assumption that an alteration in AR response could conceivably result in a change in uncomfortable loudness measures. This contention is supported in part by Morgan and Dirks (1975), who found that loudness judgements were associated with significantly higher intensity levels for high-level, low-frequency pure tones when AR activity was initiated before this stimulation than when it was not.

The subjects were asked to listen to tonal stimuli presented with the earphone and ignore the probe tone and the noise. Subjective judgements of loudness were made on a scale from 1 to 5 (1-not loud, 2-loud, 3-very loud, 4-louder but tolerable, 5-intolerable) with 5 being defined as uncomfortable loudness.

RESULTS

A. REFLEX THRESHOLDS

Table 1 summarizes the threshold estimates for AR under each condition. Subjects 1 through 6 are normally-hearing and 7 and 8 hearing-impaired. There is a noticeable effect of the NBN on the AR threshold of the PT for normals, usually in the direction of lowering the intensity level at which middle ear impedance is altered by the contraction of the stapedius muscle. This effect is statistically significant only for the noise centered at 500 Hz (Student's t-test, one-tailed analysis, $p > 0.1$ for 500 Hz PT, $p > 0.05$ for 1000 Hz PT). In addition, there is a greater difference in thresholds for the 1000 Hz PT (mean difference = 2.6 dB) than for the 500 Hz PT (Mean difference = 1,7 dB). The greater effect is seen for the tone outside of the critical ration interval for 500 Hz, although it should be noted that there was some influence exerted on tones both inside and outside of the critical ratio. The 2000 Hz NBN had no significant influence on the AR for either the 1000 or 2000 Hz tones.

There are some individual results which are of interest. In addition to the significant effects produced by the 500 Hz NBN on the 1000 Hz tone, for Subjects 3 and 6 there is also a substantial effect produced by the presence of the 2000 Hz NBN on both the 1000 and 2000 Hz tones, this being in the direction of lower AR threshold in noise.

One of the hearing-impaired subjects, number 8, was found to have a fluctuating hearing loss, so the data for these two listeners is restricted to Subject 7. Although we can not claim significant results from a sample population of one, we can suggest some general tendencies. Overall, threshold figures are comparable to those obtained from normals, although conditions which resulted in the largest threshold changes for normals (tones presented in 500 Hz NBN) produced comparatively small changes for Subject 7 (see Table 11). The greatest effect of AR threshold lowering was produced by the 2000 Hz NBN on the 1000 Hz PT. This difference was quite large (6 dB), and was, in fact, much larger than any similar measurement for normals.

B. GROWTH FUNCTIONS OF THE ACOUSTIC REFLEX

The growth of AR with increasing sound intensity is plotted in Figures 4-6. Although the levels of significance and correlation with the threshold results were not computed, some general trends may be observed. The greatest overall change appears to be produced by the 500 Hz NBN on the 1000 Hz PT, that being in the direction of greater change in susceptance at threshold and a steeper slope in the overall growth function. We see, however, that similar effects are elicited by the 2000 Hz NBN on this same tone. Also, at high intensity levels there is an increase in slope observed in the growth of reflex for the 500 Hz PT (500 Hz NBN background) and 2000 Hz PT (2000 Hz NBN background). As with previous measurements, Subject 6 demonstrated results of a much greater degree as compared to the mean, whereas Subject 3, who gave threshold figures comparable to Subject 6, remained at levels predicted by the average.

AR growth was much smaller for Subject 7 (hearing-impaired) than for the other listeners, possibly attributable to the conductive component in this subject's loss. Changes in susceptance were reflected by no more than one unit deflection on the oscilloscope at any maximum level tested (see comparable data for normals, Figures 4-6). Differences in the results were so small that one would be reluctant to interpret the significance of the results or compare them to the normal values.

C. LOUDNESS JUDGEMENTS OF PURE TONE STIMULI

As shown in Table 2, tones presented in noise tended to be rated as less loud than tones in quiet, at least near AR threshold.. In addition, tones at the maximum levels tested were judged as less loud in noise, with the exception of the 2000 Hz PT in 2000 Hz NBN, which was rated on the average as louder in noise than in quiet. These results appear to be commensurate with the data from Morgan and Dirks (1975) in which low frequency tones tended to be judged as significantly less loud when AR was elicited prior to the presentation of the tone.

Data from the hearing-impaired listener could not be analyzed appropriately because of ceiling limitations in sound pressure levels imposed by the equipment. What data could be collected was comparable to the values obtained for normals, however. That is to say, tones were judged to be about as loud as would be predicted from normative data.

DISCUSSION

In presenting these data, we are making one very important assumption, that the sound pressure of the tones and noises did not add significantly enough to produce the effects which we observed. Since it was impossible to actually measure the levels at the eardrum, additive properties of the two sounds were evaluated in a 6cc coupler (Brüel and Kjaer, #4151). Average coupler-to-eardrum transformation functions (Pollack, 1949) reveal approximately equal conversion factors for the 500 to 1000 Hz range, with the coupler slightly underestimating the pressure at the eardrum at 2000 Hz by an even larger amount. We would expect from this set of estimates to see greater addition of sound pressures for the 1000 Hz tone presented in noise centered at 2000 Hz. The fact is that the greatest effects observed on threshold and growth of AR was seen for the condition in which the coupler best predicted the state at the eardrum, that is, 500 to 1000 Hz. Assuming the coupler to be a reliable estimate of sound pressure at the eardrum for the 500 to 1000 Hz range (taking into account proper conversion factors), measurement of the levels used in determining all thresholds showed that under no circumstances did the added levels account for the threshold differences between noise and quiet. Under a very few conditions, noise and tones were observed to add by about 1.75 dB (two specific circumstances of adding together a 500 Hz NBN and 1000 Hz PT). Even with this magnitude of augmentation, the changes seen under the different determinations was greater. Most sound pressure additions were on the order of less than 0.5 dB.

One possible problem, relating to artifactual stimulation of the AR, involved the choice of probe tone (660 Hz). The Grason-Stadler

1702B otoadmittance meter maintains the sound pressure level of this tone at 85 dB SPL. This sound may have been responsible for perstimulatory contraction of the stapedius muscle bilaterally and could have influenced our results. As we found with the noise bands, this tone would not necessarily have to be above the subjects' AR thresholds (as recorded by conventional impedance audiometry) in order to exert an influence.

The discrepencies noted in AR threshold and growth between the test conditions of noise and quiet may be a manifestation of two possible mechanisms:

1. Physiological- Neurons in the reflex arc and/or fibres of the stapedius muscle may be experiencing a slight increase over spontaneous discharge, enough to sensitize them to respond more rapidly and effectively to subsequent stimuli.
2. Psychological- There may be some alteration in one's level of awareness relating to the perception of sound, its presence preparing the subject for the possibility of more intense stimulation.

It is reasonable to give more weight to the former hypothesis owing to the frequency dependencies which were found. Further investigation is needed to clearly define the causative mechanism.

Needless to say, the two explanations offered are neither exhaustive nor are they exclusive of each other. Furthermore, there is some difficulty in working with second order approximations of the effective sound level at the human ear, i.e., using a 6cc coupler to calculate interactions of the levels of the sounds employed in this study.

Given that the physiological and psychological states of the subject may influence clinical and experimental results, we can conclude that the acoustical environment might influence the psychological and/or physiological state of the subject and thus alter test fi... The amount of average change noted- on the order of 3 dB at the most- might be obscured clinically because of the relatively large steps used in evaluating patients (usually 5 dB changes). However, the results may become significant in an experimental setting where more precise techniques are employed. It is suggested that the test environment be adequately controlled for ambient noise when evaluating the AR for subjects under either circumstance, since we might expect occasional individuals to show more susceptibility to the effects of background noise, as was exemplified by several subjects in this study.

Since AR was found to occur at an average of 3 dB lower in the presence of background noise for at least one condition (500 Hz NBN, 1000 Hz PT), we might infer that there may be additional protection offered hearing aid users in this frequency region than is commonly supposed. This could influence the results of researchers who have tried to set the maximum power output of hearing aids by working from the AR response or predict uncomfortable loudness levels from the same (Berger et al., 1979). We should add, however, that this supplementary protection is available only for subjects who actually possess an AR response and would be absent for those who do not, e.g., post-stapedectomized patients.

SUMMARY

The effect of background noise on the threshold and growth of the acoustic reflex and on loudness judgments of pure tone stimuli were examined for 6 normally-hearing and 2 hearing-impaired subjects. It was found that, with the level of a narrow band of noise centered at 500 Hz presented at 10 dB below its reflex threshold, there was a significant lowering of the level at which the reflex threshold occurred and an increase in the slope of the reflex growth function for a 1000 Hz tone presented in that noise. Individual data was variable, with some subjects showing a greater influence due to the presence of the noise and others demonstrating more effect under different frequency conditions. Loudness judgments, on the average, tended to show tones being rated as less loud in noise when they were given near reflex threshold. There were various effects evident at higher levels of presentation.

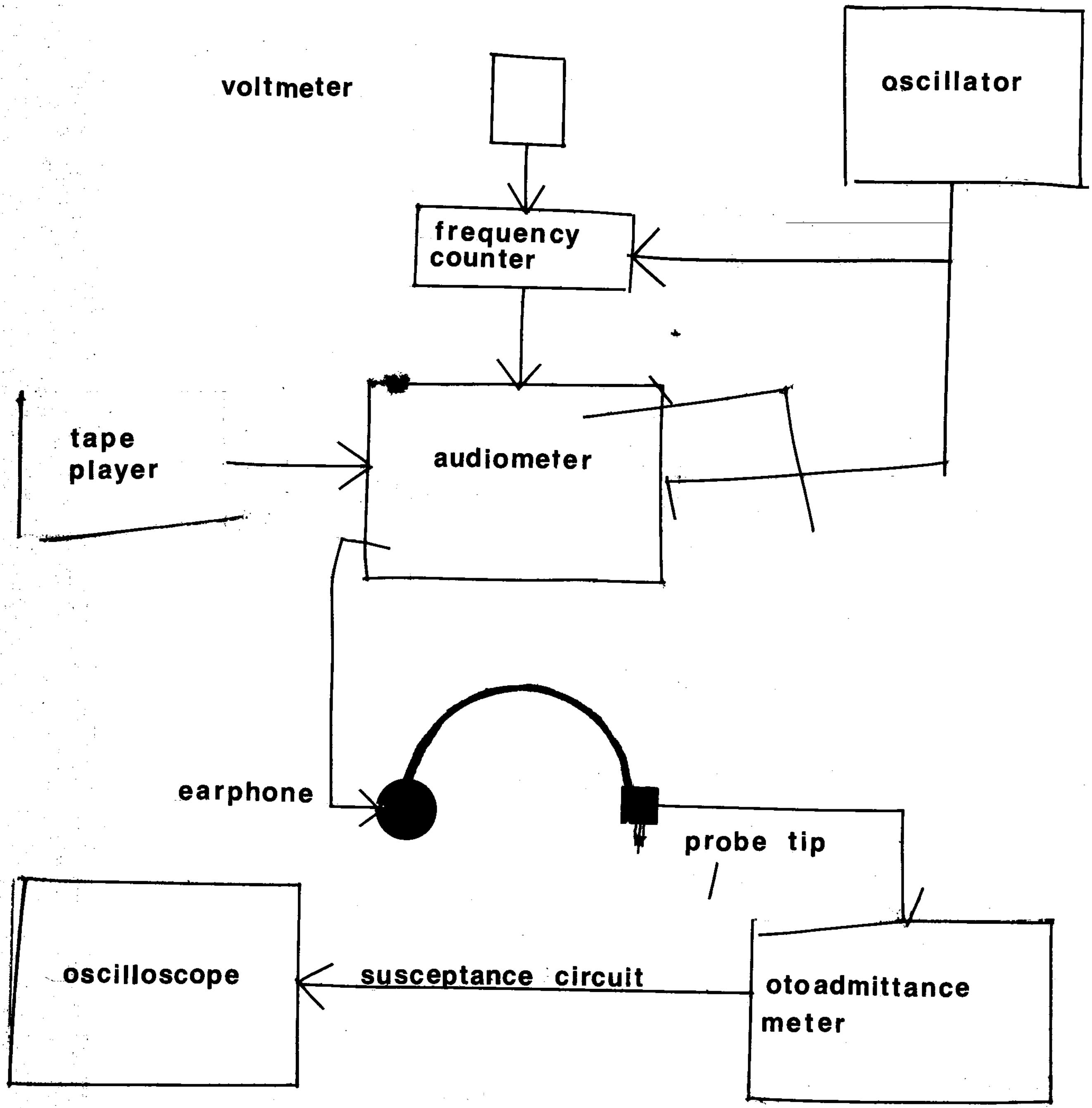

Figure 1. Experimental set – up

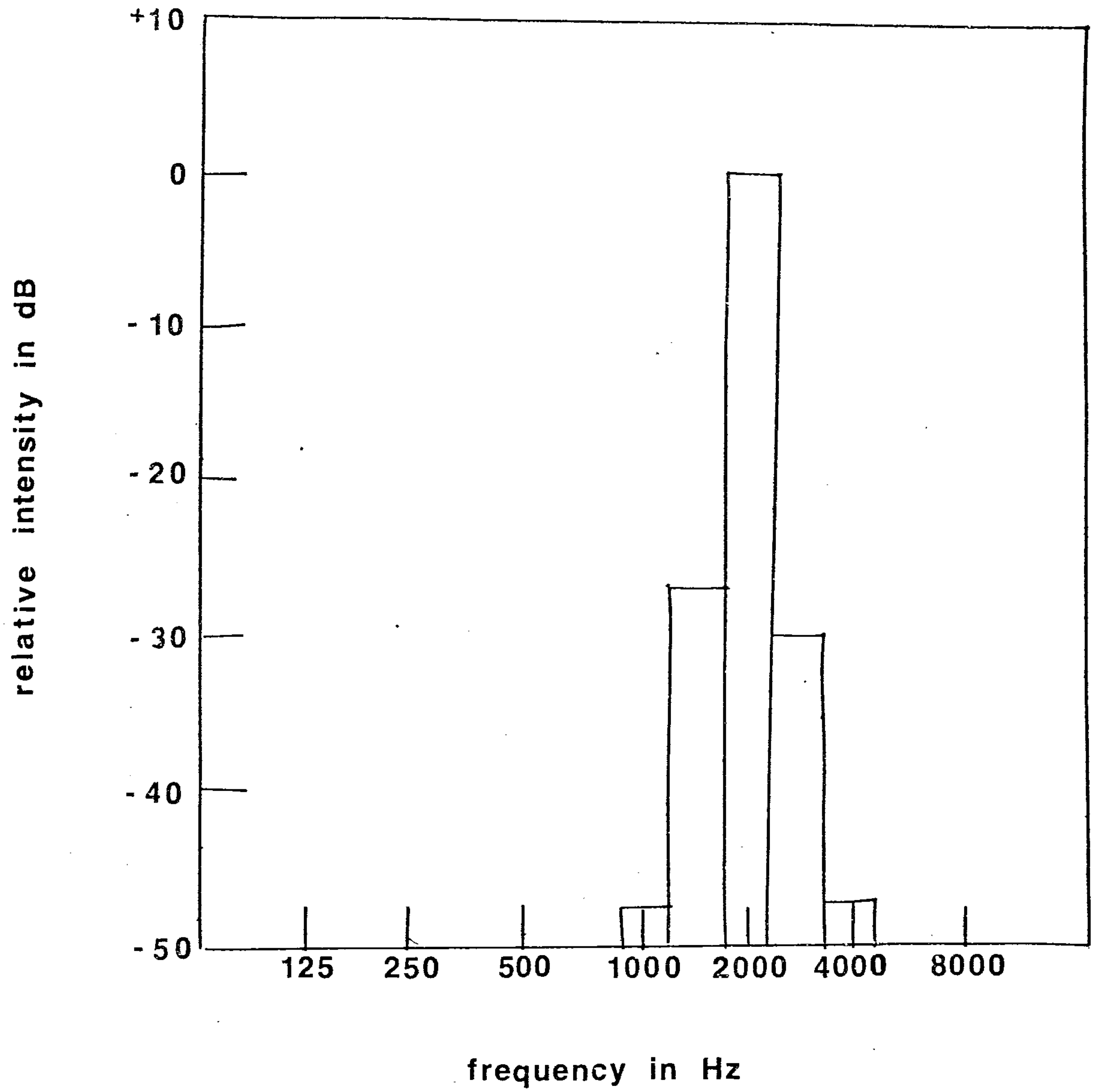

Figure 3 . One – third octave band analysis of NBN centered at 2000 Hz

subject	PT [Hz]	without noise	with noise 500 Hz NBN	with noise 2000 Hz NBN
1	500	92.5	93.5	
	1000	87.5	87.5	90.5
	2000	93.25		93.25
2	500	102.5	99.5	
	1000	—	94.5	95.5
	2000	94.25		94.25
3	500	—	97.5	
	1000	99.5	93.5	97.5
	2000	103.5		100.25
4	500	93.5	89.5	
	1000	88.5	88.5	87.5
	2000	92.25		92.25
5	500	99.5	98.5	
	1000	91.25	90.5	94.5
	2000	97.5		99.25
6	500	105.5	101.5	
	1000	102.5	96.5	98.5
	2000	101.25		100.25
7	500	104.5	103.5	
	1000	102.5	101.5	96.5
	2000	92.25		92.25
8	500	91.5	90.5	
	1000	91.5	88.5	90.5
	2000	94.25		95.25

Table 1. Thresholds for AR, with and without NBN, dB SPL re 20 μPa.

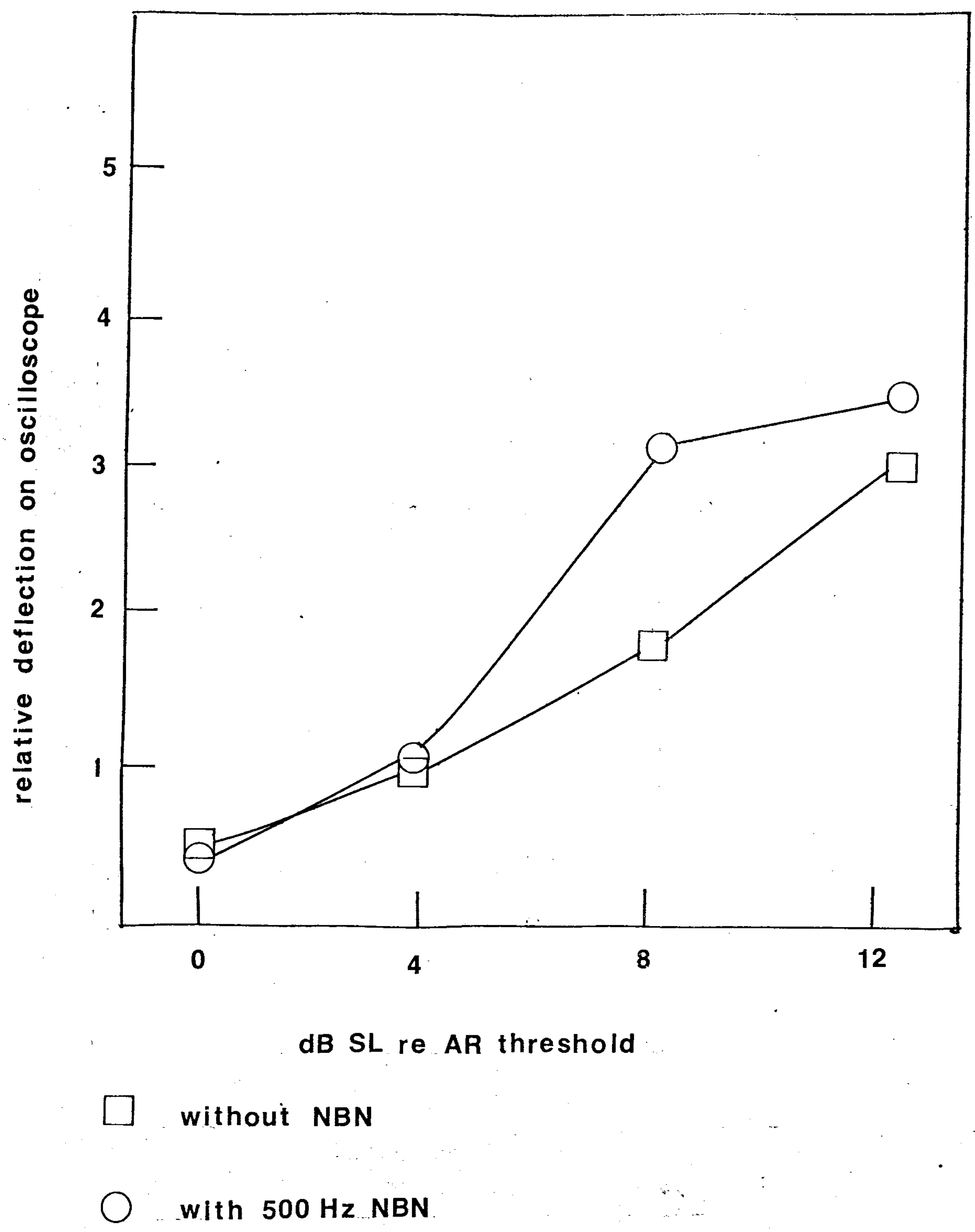

Figure 4. AR growth for 500 Hz PT, normal subjects

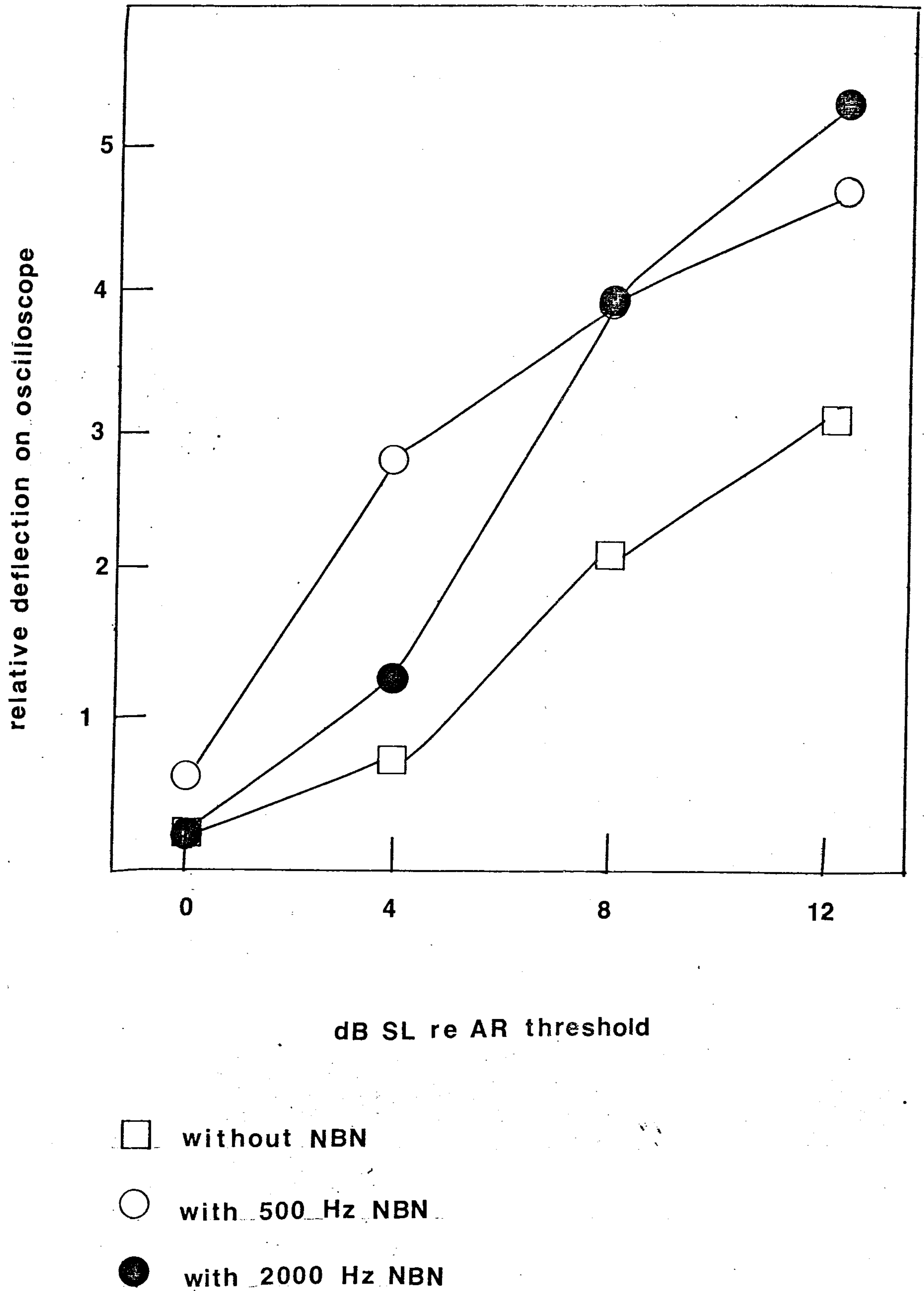

Figure 5. AR growth for 1000 Hz PT, normal subjects

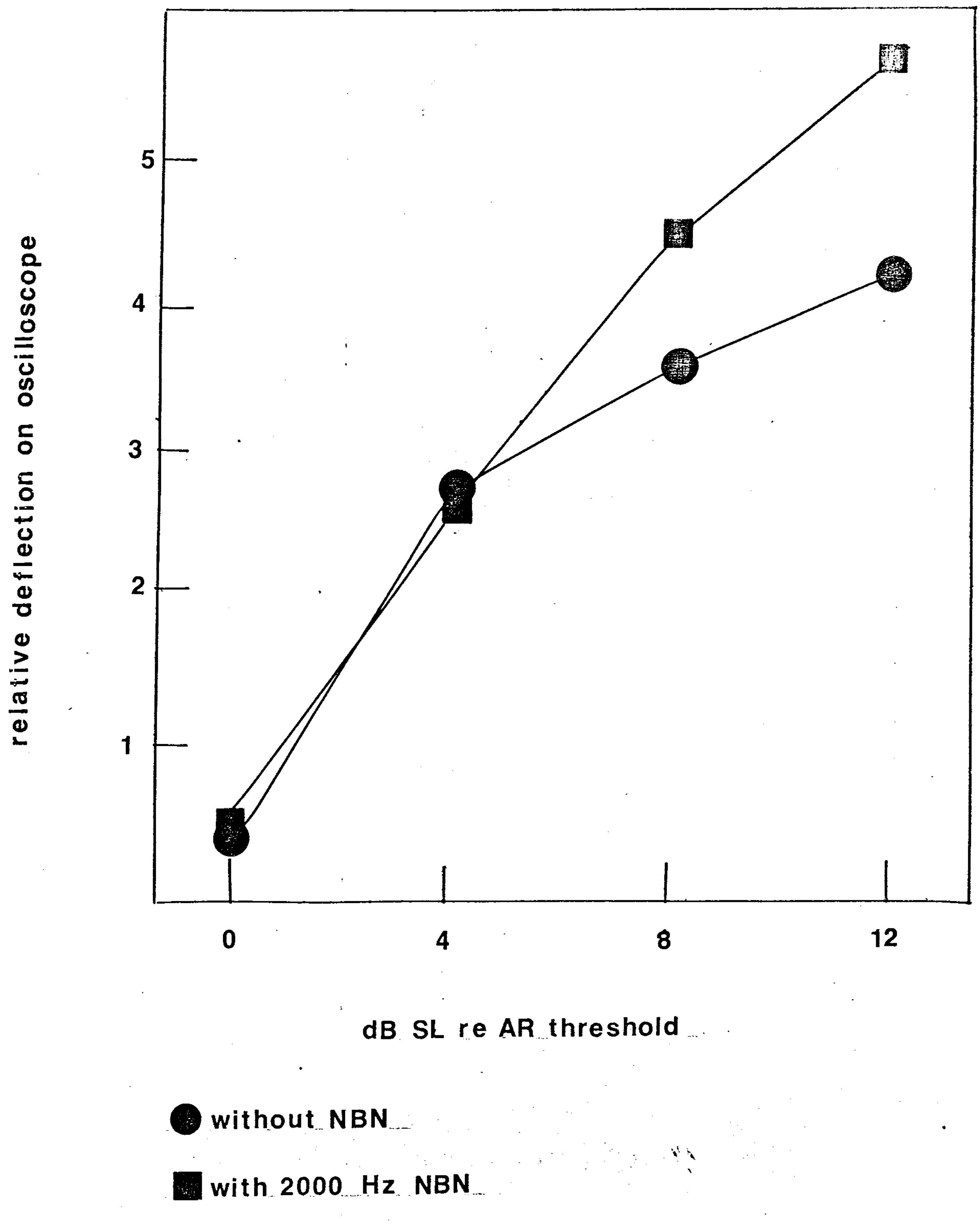

Figure 6. AR growth for 2000 Hz PT, normal subjects

500 HZ tone

quiet	1.6	1.8	2.2	3.0
* 500 HZ NBN	1.2	1.7	2.2	2.7

1000 HZ tone

quiet	1.6	2.0	2.6	3.6
* 500 HZ NBN	1.0	1.8	2.5	3.3
* 2000 HZ NBN	1.0	1.8	2.5	3.2

2000 HZ tone

quiet	1.8	2.3	2.5	3.0
* 2000 HZ NBN	1.2	2.0	2.8	3.8

1 – not loud
2 – loud
3 – very loud
4 – louder, but tolerable
5 – intolerable

* refers to center frequency of background noise in which loudness of tone was judged

Table 2. Subjective loudness judgments of tonal stimuli [mean values for 6 normally – hearing subjects].

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